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14. ABSTRACT

Large-scale Organized Structures (cloud streets and dendritic formations, LOSs) are common in the Marine Boundary Layer (MBL) when wind shear and MBL stability are favorable. We found that the continuous wavelet transform was an effective way to characterize LOSs from in-situ data. Compared to unorganized convection, LOSs enhance exchange with the free troposphere and are more effective at distributing seasalt aerosol throughout the MBL. Since relatively particle-rich updrafts occur under cloud, satellite data are likely to underestimate optical effects of aerosols in the MBL.

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Final report: ONR Research Award N00014-12-1-0965: Connecting tropical marine cloud structures to boundary layer properties and the effect of sea state on whitecap coverage

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1 Long-Term Goal

Our long-term goal is to establish an improved understanding of the factors that control the marine aerosol properties and concentrations as they relate to generation processes, mixing processes, their dependence on oceanic and environmental conditions and physicochemical evolution in the marine boundary layer. We expect these efforts to lead to improved modeling and predictability of marine aerosol concentrations and optical properties.

2 Objectives

During the PASE project in 2007, we noticed that tradewind cumulus clouds in the area near Christmas Island sometimes appeared unordered, and other times in cloud streets. This was accompanied by changes in aerosol properties. Our aim here was to explore the circumstances controlling the appearance of these Large-scale Organized Structures (LOSs) and their effect on aerosol production, concentration and vertical distribution (and consequently on optical extinction).

3 Approach

It is often difficult to determine whether clouds are organized when one is among them. We used satellite imagery to classify regions we flew through as unorganized, dendritic, or rolls (also called cloud streets.) Figure 1 shows typical examples. We looked at how boundary layer depth, winds, and aerosol concentrations changed in these circumstances.

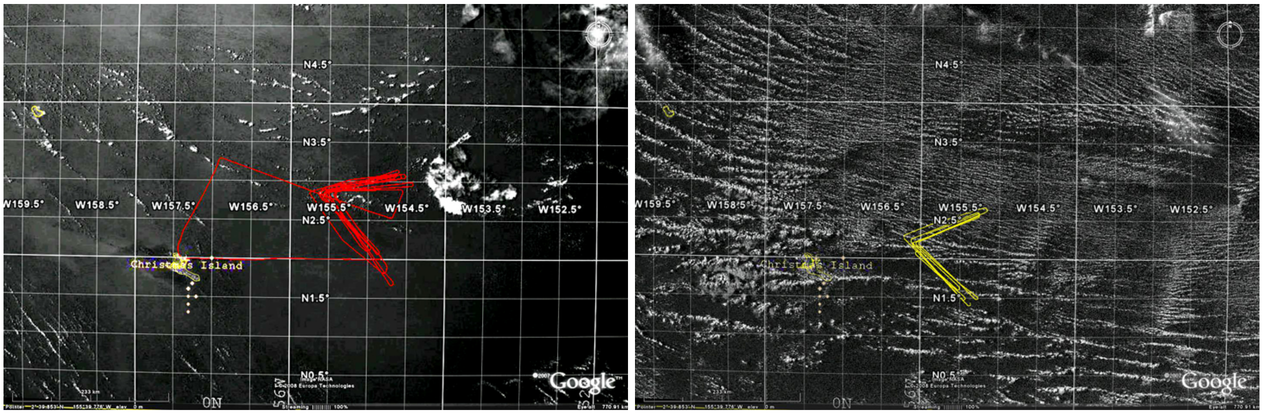

Figure 1: Cloud structure patterns during PASE: GOES-11 imagery with flight tracks superimposed. Left, unorganized cloud, from flight 8, Right, rolls (north part of flight track) and dendrites (southern part of track) from flight 14.

Fourier analysis is typically used to measure fluxes under turbulent conditions, but the large scale of the structures render the requirement of homogeneity difficult to satisfy. Instead, we used a Continuous Wavelet Transform (CWT) as it can extract both frequency and time (position) information from nonstationary time series . The CWT provides a means to separate different structures of a time series with different frequencies at different times and therefore is well suited to analyze processes in the unsteady and inhomogeneous MBL.

4 Work completed

In this project, we were funded for one year to explore these phenomena further. The project really ended in May 2013, though for bookkeeping reasons it formally continued through April 2015. Unfortunately, Vladimir Kapustin, who was doing the work, was forced to retire early due to health problems, and never managed to get the resulting paper into publishable form. Before he retired, Vladimir had largely completed his analysis and had a paper in draft form. The findings are summarized here.

The wavelet analysis effectively showed the spatial scales of the types of cloud structures (Figure 2). These scales were 3 km to 6 km (30 s to 60 s at $100\,\mathrm{km\,s^{-1}}$) for rolls and >10 km for dendrites.

The nature of the LOSs was strongly influenced by the stability of the mixed layer. If the sea surface temperature exceeded the air temperature (encouraging instability), either dendrites or unorganized clouds were present. If $T_{\mathrm{air}} - T_{\mathrm{surface}} > 0.25\,°\mathrm{C}$ then rolls formed (Figure 3). This is reinforced when looking at the bulk Richardson number, the ratio of atmospheric stability to wind shear [Brümmer, 1999]:

$$\mathrm{Ri} = \frac{g}{\theta_v} \cdot \frac{\Delta\theta_v Z_i}{U_z^2} \tag{1}$$

where g is gravitational acceleration, θ_v and $\Delta\theta_v$ are the mean and change in virtual potential temperature across the surface layer with thickness Z_i, and U_z is the wind speed at the top of the layer. For Ri $<\sim 0.3$ rolls were always present (Figure 4).

As one might expect, organized convection deepens the boundary layer, increasing seasalt aerosol concentrations, and enhances exchange with the free troposphere. As shown in Figure 5,

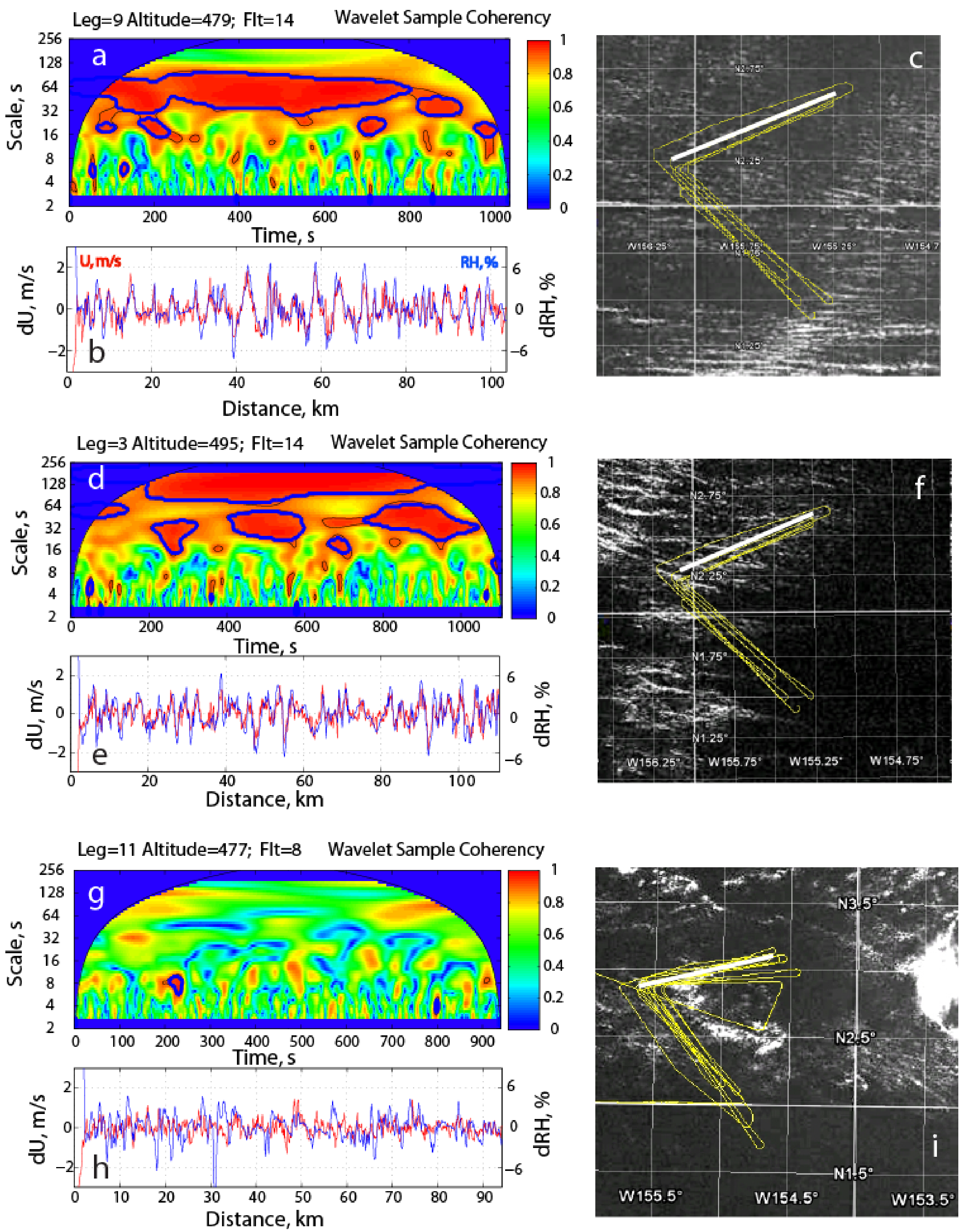

Figure 2: Time series of horizontal wind component dU (red) and relative humidity dRH (blue), the corresponding wavelet coherence cospectra (2D plot) and corresponding GOES satellite image with 100km flight leg (white) for a well developed rolls case (top panels), rolls and dendrites (middle panels) and case without rolls (bottom panels). Red areas outlined in blue satisfy the areawise test for significance [Maraun et al., 2007].

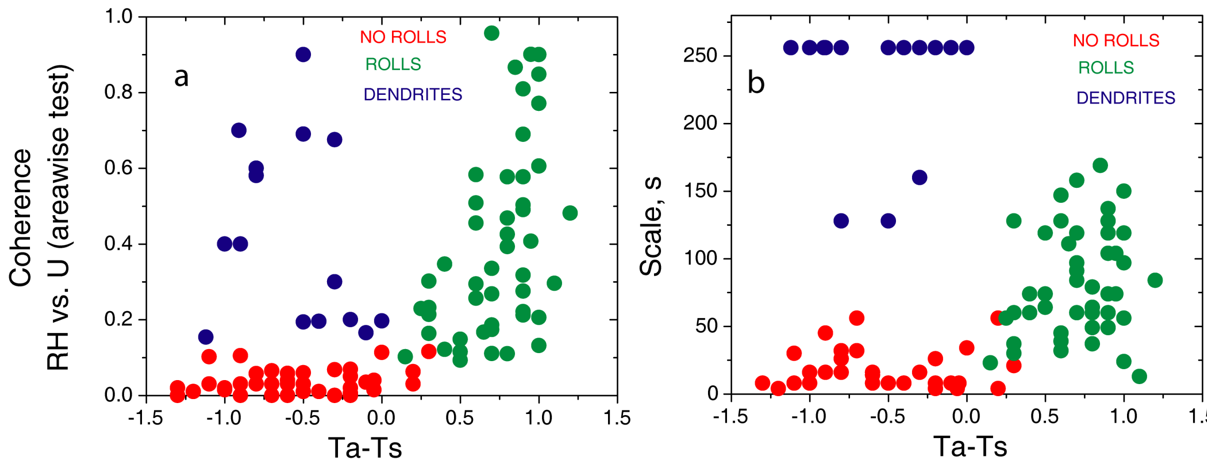

Figure 3: Amplitude (a) and scale (b) of integral coherence wavelet cospectra of U and RH as a function of $\Delta T = T_{\rm air} - T_{\rm sea\ surface}$. The areawise test is applied for integral wavelet coherence cospectra estimates.

coarse and fine particles are mixed more uniformly and to higher altitudes when rolls and dendrites are present.

While we have emphasized PASE here, we have found rolls in other projects, including MILAGRO, over the Gulf of Mexico in 2006 and often around Hawaii.

5 Related Projects

No related projects.

References

B. Brümmer. Roll and cell convection in wintertime Arctic cold-air outbreaks. *Journal of the Atmospheric Sciences*, 56(15):2613–2636, 1999.

D. Maraun, J. Kurths, and M. Holschneider. Nonstationary Gaussian processes in wavelet domain: synthesis, estimation, and significance testing. *Physical Review E*, 75(1):016707, 2007.

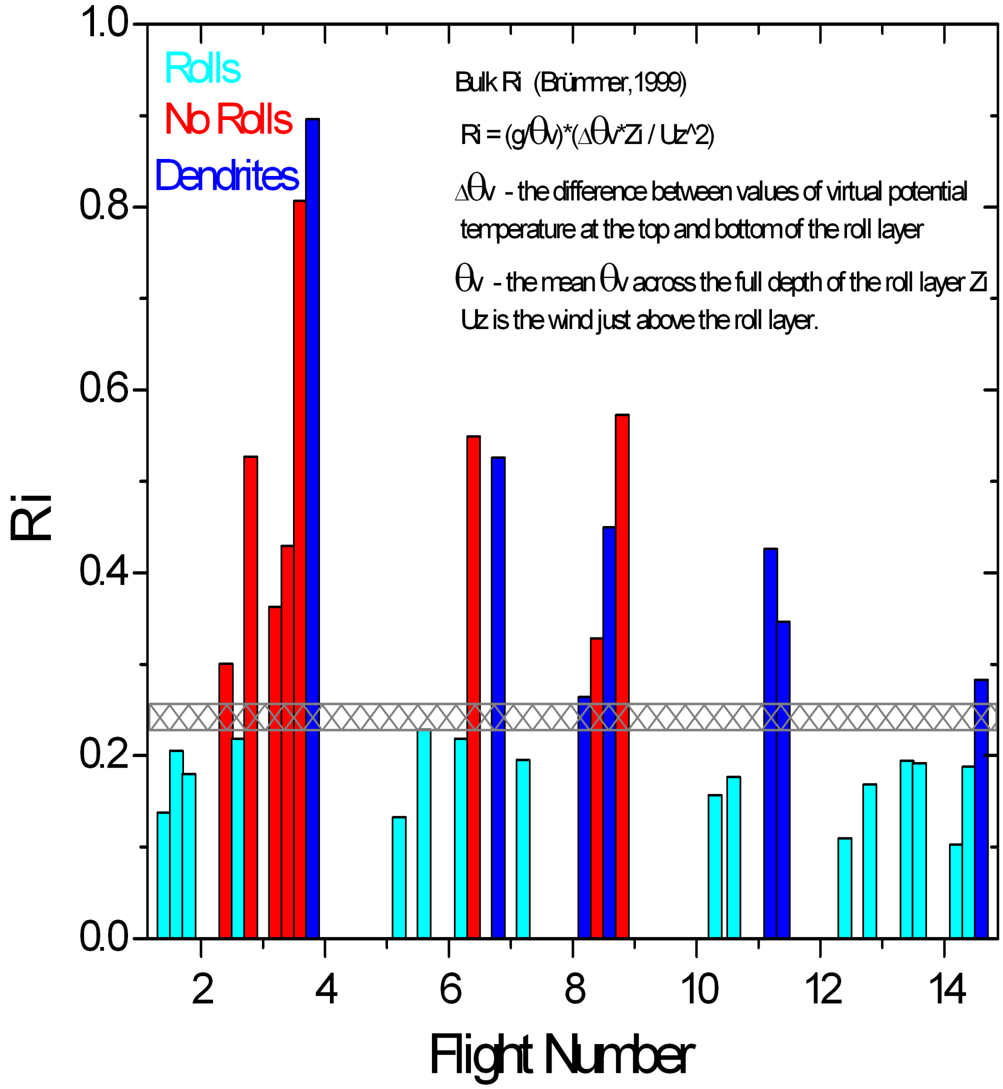

Figure 4: Richardson numbers derived from vertical profiles during PASE and corresponding cloud structures.

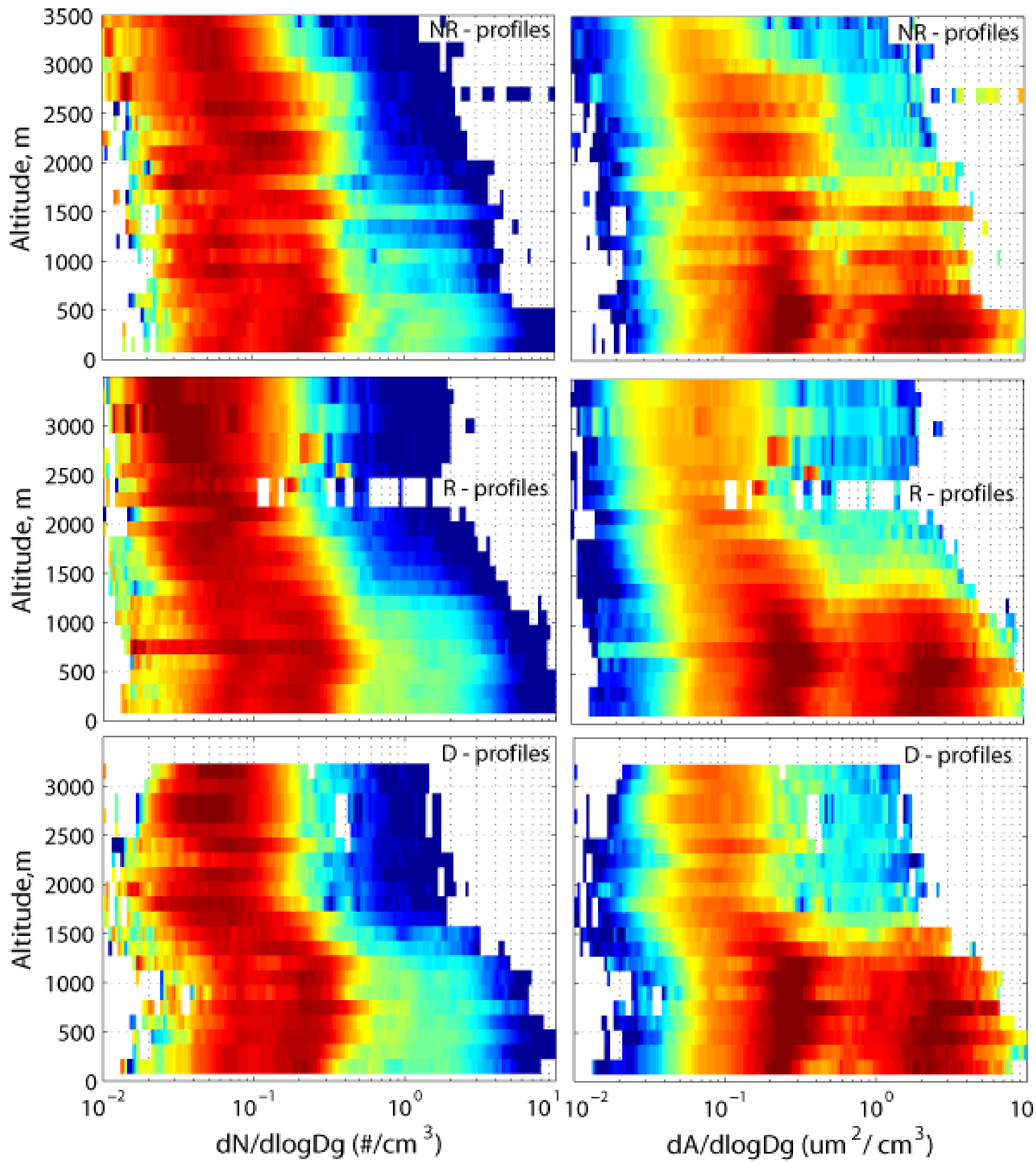

Figure 5: Median 2D vertical profiles of ambient number (left panels; colored by $dN/d\log D_p$) and area (right panels; colored by $dA/d\log D_p$) size distributions for No Rolls/Small Rolls (top), Developed Rolls (middle) and dendritic formations (bottom). Area distributions are shown to emphasize the coarse (seasalt) mode.